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FINAL REPORT

FOR

TORCH LAKE

HOUGHTON, MICHIGAN

NOV 2 6 1991

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INTRODUCTION

Site Background

Torch Lake is a lacustrine system located on the Keweenaw Peninsula in Houghton County, on the Upper Peninsula of Michigan, approximately five miles north of the city of Houghton and adjacent to the town of Lake Linden at its northern extremity. It is connected to Portage Lake, which is part of the Keweenaw waterway that bisects the Keweenaw Peninsula and communicates with Lake Superior at both ends. Torch Lake has a surface area of 2,717 acres, a mean depth of 56 feet, and a maximum depth of 115 feet. Located in Michigan's copper district, the lake was the site of milling and smelting facilities, served as a repository for copper mining and milling wastes (stamp-sands), and was used for transportation to support the copper industry from 1867 until 1968. Piles of copper tailings extend into the lake from the sites of these defunct smelting operations situated on the northwestern shore. Industrial spills of cupric ammonium carbonate (copper leach liquor), a compound utilized in copper processing, occurred in the northern end of the lake in October, 1971 and early June, 1972.[1] The bottom sediment of the lake is primarily derived from stamp-sands which are reddish-gray in color, clay-sized, of low organic content, and contain in excess of 0.1 percent copper.[2][3] Torch Lake presently receives the non-contact cooling water discharge from the Peninsula Copper Company, a copper reclamation operation. Torch Lake is also used for recreational purposes. Copper concentrations have been reported to range from 0.13 to 0.26 percent in the sediment and from 25 to 87 micrograms per liter (ug/l) in the water column.[2]

The United States Environmental Protection Agency/Environmental Response Team (U.S. EPA/ERT), supported by the Response Engineering Analytical Contract (REAC) and the Environmental Response Team/ Technical Assistance Team (ERT/TAT), performed a drum search, utilizing a Remotely Operated Vehicle (ROV), and conducted a limited surface water quality investigation at this site on August 3, 1989. Drums were located by the ROV, at depths ranging between 6 and 15 feet. The results of chemical analysis of the surface water indicated minimal contamination by semi-volatile organic compounds.

Objectives of the Study

The objective of the study was to determine both acute and toxic effect levels in the sediments of Torch Lake. The study was devised to evaluate, not only copper toxicity but if other variables such as mercury and variations in site sediment parameters were contributing to or ameliorating toxic effects. Sediment samples were collected, screened by X-Ray Fluorescence (XRF) for copper and stored so that a site specific gradient of copper could be evaluated for toxicity. Other tasks included,

collection of surface water samples for metals analysis and toxicity testing by the U.S. EPA Region V.

METHODOLOGY

Field Schedule and Personnel

The field investigation was conducted from May 20 through 23, 1991. Personnel present on site included Walter Neid (U.S. EPA Region V On-Scene Coordinator), David W. Charters (U.S. EPA/ERT Work Assignment Manager), Harry Compton and Alan Humphrey (ERT Dive Team members), Tex Irvin (Michigan Department of Natural Resources (MDNR), William VanDerveer (REAC Task Leader), Mark Bernick, Sally Mayasich, David Mickunas, Kenneth Munney, and Denise Remeta (REAC Field Team Members), and Karen Kracko (ERT/TAT Field Team Member).

Sediment Sampling

Four, 4 ounce (oz.) sediment samples were collected utilizing a stainless steel petite ponar dredge at random locations offshore of the demolished smelter. These samples were used to check the x-ray fluorescence (XRF) equipment. Comparisons were made between wet samples and dried samples to evaluate the need to dry each sample. Based on these results, it was determined that sample drying would improve the XRF results.

Sediment samples were collected at 22 locations throughout Torch Lake and three locations within Portage Lake (Figure 1). Sampling was conducted utilizing a standard (9 x 9 x 9 inch) stainless steel ponar dredge operated from a davit aboard the 25-foot U.S. EPA/ERT workboat. Following collection, the contents of the ponar dredge were placed in a stainless steel pan, the surface water was then gently poured off in an effort to retain the fine particulate components of the sample, and the sample was then homogenized. The sample was then transferred into the appropriate sample containers. Each sample set consisted of one, 4 oz. jar for XRF analysis, one, 8 oz.jar for Target Analyte List (TAL) metals and total organic carbon (TOC), one, 32 oz. jar for particle size distribution, and one, 32 oz. jar and one, 8 oz. jar for 28-day solid phase chronic toxicity testing utilizing the amphipod, *Hyalella azteca*. Following their collection, the samples were preserved on wet ice (4° Centigrade (C)) and the XRF samples were shuttled to the staging area, where they were prepared and analyzed. Sediment sampling equipment was decontaminated between locations with an initial rinse with soapy water followed by potable water, 10 percent nitric acid, and distilled water rinses.

Locations were mapped relative to landmarks or approximated using a rangefinder and described on the field data sheets and/or personal logbooks (Figure 1).

XRF Instrumentation and Calibration

A portable Outokumpu Electronics Inc. (OEI) X-MET 880 XRF analyzer with a Dual Source Heavy Element Surface Probe fitted with a Cm-244 and a Am-241 radioisotope source was used for analysis of lake sediment samples for copper. The XRF instrument was calibrated for copper analysis with chemically analyzed site specific sediment samples according to the instrument's operating manual. The results of the chemical analysis of the site specific sediment samples are presented in Table I. The XRF calibration curve was verified by analyzing low, mid, and high calibration standards.

XRF Sediment Preparation and Analysis Method

Sediment samples were homogenized in the sample jars for one minute using a stainless steel spoon. Approximately one-half ounce of homogenized sediment was placed in an aluminum weigh boat and dried in an oven for one hour. The sediment was broken up and then passed through a 20-mesh stainless steel sieve. Organic matter and gravel were removed and discarded. For each sample measured, a 31-millimeter (mm) polyethylene X-ray sample cup was labeled, filled with sediment, and sealed with a piece of 0.2 mm thick polypropylene X-ray film.

Prior to the XRF analysis, the sample cup was gently tapped against the table top three times to pack the sediment evenly against the window film. The sample cup was placed directly on the XRF detector window and the instrument initialized for a sixty-second analysis for copper. The sample number and the XRF analytical results were recorded in the XRF laboratory notebook. The sample in the cup was then mixed by rotating the cup for thirty seconds and tapped against the table top three times to pack the sediment evenly against the window film. The sample was reanalyzed by XRF for copper, mixed a second time, tapped against the table, and reanalyzed by XRF a third time. The results of the three analyses were averaged and reported to two significant figures.

Selection of Samples for Toxicity Tests

Based on the copper concentration of the sample, as determined by XRF, (Table 2), ten of the twenty-five sediment samples were selected for evaluation of TAL metals, TOC, grain size, and solid phase toxicity. These ten samples were collected from Locations 1, 4, 5, 6, 8, 9, 10, 13, 19, and 23 (Figure 1).

Surface Water Sampling

In-situ water quality data was collected at multiple depths in random locations with a Hydrolab Surveyor II. Water quality data and surface water samples were collected at Water Sampling Locations (WSL) 1 through 5 (Figure 1). These locations were estimated and documented in the same fashion as the sediment sampling locations. All water samples were collected one foot above the lake floor with a 3.2-liter (1) acrylic Kemmerer bottle.

At all locations, a 1-1 polypropylene bottle was filled for TAL metals analysis and preserved with 40 percent nitric acid to a pH<2. At WSL 1 and 5, two, 1 gallon (gal.) cubitainers per location were also filled. At WSL 2, 3, and 4, one, 5 gal. cubitainer per location was also filled at the request of U.S. EPA Region V. A rinsate blank for TAL metals analysis was collected immediately following the completion of surface water sampling activities and equipment decontamination. In addition, a ponar dredge rinsate blank was collected for TAL metals analysis and preserved in the same manner. All samples were maintained at 4°C with wet ice. Water sampling equipment was decontaminated between WSLs utilizing soap, potable water, 10 percent nitric acid, and distilled water rinses.

All samples to be analyzed, including sediment and water, were packed and shipped to their respective laboratories via Federal Express. The remaining sediment samples were returned to the site.

RESULTS

Sediment Sampling Results

TAL metals analysis by Atomic Absorption methods revealed quantifiable levels of 21 analytes in the sediment (Table 1). Elevated levels of several heavy metals were identified throughout the study site. Copper ranged from 24 milligrams/kilogram (mg/kg) at Location 10 to 23,000 mg/kg at Location 13. Mercury ranged from non-detect (<0.02 mg/kg) at Location 10 to (0.46 mg/kg) at Location 13. The highest levels were detected at location 13, the sampling location below the discharge point of the Peninsula Copper Company. A general trend, observed in samples analyzed from the site, is that most of the metal concentrations tended to increase as the copper concentration increased. The total metal burden ranged from 3,623 (Location 10) to 176,284 (Location 13) mg/kg.

Correlation analysis was performed for all 21 analytes to determine if any metals were co-located (Table 3). This analysis revealed significant ($P \leq 0.05$) positive correlations between copper and antimony, arsenic, barium, cadmium, chromium, iron, lead, mercury, nickel, silver, sodium, and zinc. In addition, numerous highly positive correlations were identified amongst most of the heavy metals other than copper.

Analysis of particle size distribution revealed two general types of samples, samples dominated by fine particles and samples dominated by coarse particles (Table 4). Correlation analysis failed to correlate high copper concentrations with fine particle size. In addition, it was noted by the analyst that the coarse components of the samples from Locations 4 and 6 were largely organic. It was not noted whether these organics were of detrital origin or if they were macrophytes entrained in the dredge during sampling.

The TOC content of the sediment samples was extremely variable, ranging from 870 mg/kg at Location 10 to 130,000 mg/kg at Location 4 (Table 5). Correlation analysis did not identify a relationship between TOC and copper concentration.

Toxicity Testing Results

Visual observations of the testing chambers, by the analyst, enabled an estimation of acute toxicity responses. These observations provide non-definitive acute toxicity data due to the burrowing nature of *H. azteca* which enabled only dead individuals on the surface of the sediment to be enumerated. These observations were made every 24 hours for the first 72 hours of the test, and revealed high mortality in sediment samples from Locations 6 and 13 (Table 6). Low mortality was observed in samples from Locations 1, 4, 9, 10, 19, and 23. In addition, no mortality was observed in samples from Locations 5 and 8 as well as the sediment and leaf controls. At the termination of the tests, percent mortality was determined for each location.

Chronic toxicity of these samples was determined by organism growth, expressed as mean increase in dry weight and mean increase in body length (Table 6). These parameters were quantified for the tests run on samples from Locations 8, 9, 10, and 19 as well as the sediment and leaf controls. Complete mortality in the other samples precluded performing these biometrics. Initial organism weight was neither measured nor estimated, but was assumed to be homogeneous, thus, growth expressed as increase in weight can only be evaluated through comparison with the test controls.

ASTM solid phase sediment toxicity test minimum control survival of 80 percent was utilized. The sediment control met the minimum acceptability standard of 80 percent survival, whereas the leaf control, with a mean survival of 48 percent, failed to meet these criteria and was rejected (Table 6).

Statistical Comparison of Sediment Chemistry and Toxicity Data

Lethal Concentration$_{50}$s (LC$_{50}$s) were calculated for sediment-bound copper and mercury based on the results of the toxicity tests using probit analysis and the Trimmed Spearman Karber Test. The LC$_{50}$ for copper as the sole contaminant was calculated as 498 with a 95 percent confidence range of 480 ppm to 520 ppm. The Probit analysis calculated an LC$_{50}$ of 520 with a 95 percent confidence range of 400 ppm to 630 ppm.

Growth based on mean replicate length and weight of *H. azteca* was measured and statistically compared utilizing a one-tailed t test, performed by the laboratory. Only Location 10 was not significantly different from the controls in body weight and length. All other Locations with surviving amphipods were significantly different in both respects.

Surface Water Sampling Results

TAL metals analysis identified 10 analytes present at quantifiable levels (Table 8). The concentrations of most of these metals were generally homogeneous. Copper was elevated at WSL 1 and mercury was present at WSLs 1 and 4. Lead was present at WSLs 1 through 3 at up to 8 ug/l. Calculated surface water hardness averaged 45.31 mg/l (CaCO$_3$) and ranged from 44.81 at Location 5 to 46.05 at Location 1 mg/l (CaCO$_3$) (Table 8).[5]

In-situ water quality measurements at the WSLs 1 through 5 and the random locations showed variations among locations in temperature with depth and relative homogeneity in pH, dissolved oxygen (D.O.), conductivity, or oxidation reduction potential (ORP) between locations or between depths at the same location (Tables 9 and 10). Salinity at all locations and depths was zero. Based on these measurements, an approximate temperature profile is depicted in Figure 3. The data does not indicate the presence of a distinct thermocline.

DISCUSSION OF RESULTS

Chemistry and Toxicity of Copper and Mercury in Aquatic Ecosystems

Copper is a naturally occurring free metal possessing a characteristic reddish color. In animals, copper is an essential nutrient utilized in more than 12 specific proteins, hemoglobin formation, carbohydrate metabolism, and cross-linking of collagen, elastin, and hair keratin. Other metals such as zinc, iron, and molybdenum may interact with copper to affect its absorption, distribution, metabolism, and utilization.[6] Copper toxicity can, thus, vary greatly with the chemical species of the metal and the physical and chemical characteristics of the water.[2] In aquatic ecosystems, copper may exist in several forms, many of which are exhibit relatively low toxicity. Only ionic copper (Cu(II)) is considered a significant ecotoxin.

Copper toxicity to biological systems may stem from copper ions binding to the cytoplasmic membrane, thus, arresting cell division. Animals vary in their copper uptake potential and tolerance with species, age, reproductive condition, and physiological condition. There is also a great variation in uptake mechanisms and sensitivity to this contaminant[7]. Other cations, such as calcium (Ca(II)) and magnesium (Mg(II)), tend to displace copper and reduce its toxicity. Acute toxicity has been shown to decrease as water hardness and alkalinity increase, however, chronic toxicity is not strongly affected by these properties.[6] Mollusks, crustaceans, and mayflies are especially sensitive to copper.[8]

Cairns et al., 1984 performed copper spiked sediment toxicity tests with benthic invertebrates (including *H. azteca*) and concluded that toxic effects occur when the copper is mobilized from the sediments into the water phase[9]. The relative distribution of copper

into the water phase[9]. The relative distribution of copper between the two phases appears to be controlled by equilibrium kinetics[10]. The partioning results in a positive correlation i.e., the higher the sediment levels the higher the interstitial water concentrations. Cairns et al., proposed that solid-phase LC_{50} values for copper are the sediment copper concentrations that correspond to LC_{50} values for dissolved copper at equilibrium for a given sediment type.[9] It is apparent that higher sediment concentrations would result in increased soluble ion concentrations, however, Cairns et. al., did not consider the route of exposure in the case of deposit feeding biota such as *H. azteca*. While the solid-phase and liquid-phase bioassays may exhibit a positive correlation, exposure through ingestion in deposit feeders must be considered a significant exposure. This study evaluates copper toxicity to *H. azteca* from both perspectives.

Previous studies on sediment-bound copper, existing as stamp-sands in Torch Lake and the Keweenaw Waterway have attributed laboratory toxicity, histopathological responses, and alterations in benthic community structure to copper exclusively[2,12,13,16]. These studies have shown numerous biological responses to elevated copper concentrations. The LC_{50}s calculated from this study compare well with the results from previous tests conducted on copper contaminated sediments. The actual site sediment tests conducted for this study tend to have lower LC_{50}s than the sediment spiking tests conducted by Cairns et al. but agree with the results of field collections. Surveys by Sypniewski 1977, Kraft 1979, and Kraft and Sypniewski 1981 show that amphipods are present at copper concentrations above 33 mg/kg but are absent above 588 mg/kg. The amphipod, *H. azteca* used in the toxicity tests are not equivalent to the amphipod Pontoporeia hoyi surveyed by Kraft and Sypniewski but they are an appropriate indicator species.

High levels of sediment-bound copper were found to severely reduce the density of *Pontoporeia hoyi*, the most abundant amphipod in the Great Lakes region.[18] In addition, *P. hoyi* was absent where the copper concentration was $\geq$ 395 mg/kg.[15][18] In the northern end of the Keweenaw Waterway (average 589 mg Cu/kg) *P. hoyi* was absent and benthic macroinvertebrate diversity was reduced, whereas at the southern end (average 33 mg Cu/kg) *P. hoyi* were widespread and abundant and benthic diversity was significantly higher.[13]

Sediment Chemistry

Elevated levels of several heavy metals were identified throughout the lake with the exception of Location 10, located at the southeastern shore near the mouth of Portage Lake. While still remaining on Torch Lake, this area is the farthest away from the historical milling and smelting operations and is flushed by water from Portage Lake. It is likely that stamp-sands dumped into the lake had precipitated out of the water column prior to reaching that area or were flushed away. The absence of correlation between particle size and copper concentration is in contradiction with

but is in agreement with Kraft and Sypniewski, 1981 [13] where copper and particle size was not correlated. The wide variability in TOC concentrations may be due to the presence of large pieces of detritus or macrophytes similar to those identified in the particle size samples. TOC concentration was markedly lower at Locations 10 and 19 where sand comprised greater than 93 percent of the samples, copper concentrations were lowest and third lowest, respectively, and mercury concentrations were lowest.

Toxicity Testing

The laboratory reported that the overlying water in the leaf controls developed a dark brown color, suggesting that tannic acid and other leachates were released from the leaves resulting in high mortality. Although the leaves utilized in the control test were dried then presoaked, they apparently retained a significant amount of tannins which were released upon placement in the control chambers. The high mortality of this control was most likely a function of tannin leaching which could not occur in the other chambers, thus, this set of controls was rejected.

The 96-hour aqueous reference toxicant test identified an LC_{50} for cadmium chloride of 7.02 ug/l. These results compare closely with those of Nebeker et al., 1986[14] who reported an LC_{50} for cadmium chloride of 8 ug/l. The similarity between the Torch Lake test and the previously reported data indicates that the amphipods were healthy yet appropriately sensitive to the toxicant.

Of the samples tested, only sediment from Locations 10 and 19 did not demonstrate statistically significant differences in survival and growth in body length from the control tests. Sediment from Location 10 was the only sample that was not significantly different in growth in body weight from the control tests. Based on these findings, it appears that a toxic component is present in the sediment at Locations 1, 4, 5, 6, 8, 9, 13, and 23 which is either absent or present in a relatively low concentration at Location 10 and a slightly greater concentration at Location 19.

The primary objective of this study was the evaluation of a sediment-bound copper gradient. The gradient was evaluated for toxicity using Hyalella azteca. Copper concentration within the samples and toxic responses observed in Hyalella azteca showed a typical dose response curve (Figure 2). The LC_{50} values derived from the sediment toxicity data support the conclusion that the toxicity is induced by sediment-bound copper.

Based on the information available from this study the toxicity can not be definitively linked to only copper. Mercury while significantly correlated does not appear to be the primary toxin, but may be acting in an additive or synergistic role. Hyalella azteca is exposed to the environment in more ways than the equilibrium model accounts, including ingestion. As with other amphipods ingestion is a significant route of exposure in deposit feeding organisms. The amphipod Hyalella azteca is utilized as an

indicator of ecological response to sediment-bound contaminants primarily because it burrows into the sediment but also because it digests bacteria and algae from ingested sediment particles less than 65 um in size [20]. These characteristics make it an ideal test organism because it measures the response of internal exposure through ingestion as well as frequent contact exposure.

The equilibrium models estimate interstitial water concentration at particular sediment concentrations. There were no measurements of interstitial water during this study. In water column samples collected from Torch Lake, copper and mercury were found to be in excess of the 1986 U.S. EPA quality criteria for the protection of aquatic life.[8] Copper was found to be in excess of these criteria at WSL 1 only. The acute criteria for copper is 8.4 ug/l not to be exceeded over 24 hours within a given three year period. The chronic copper criteria is 6.0 ug/l not to be exceeded over four days within a three year period. Based on the concentrations of copper in the water column during this study, copper concentrations throughout the lake are in excess of the acute and chronic criteria for copper for the protection of aquatic life.

Mercury was found at only two water sampling locations (1 and 4), however, concentrations exceeded the U.S. EPA chronic water quality criteria. The chronic criteria for mercury states that concentrations should not exceed an average of 0.012 ug/l over a four day period within a given three year period. These levels could be responsible for some additive effects to the toxicity of copper.

CONCLUSIONS

Based on the toxicity evaluation of Torch Lake and the extent of contamination survey delivered to ERT by Region V Project Manager Jae Lee, it is apparent that the vast majority of the sediments in Torch Lake are toxic and not able to support a normal benthic community. The benthic macroinvertebrate community is an integral part of the base of a complex foodweb in a lacustrine system and a severely impacted benthic community would impact the entire foodweb. Unfortunately, the area impacted by the copper contamination may make a complete restoration of the lake to a pre-mining state unfeasible. Alternate proposals should be entertained including remediation of portions of the lake. Studies of these alternate possibilities should be undertaken as soon as possible.

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LEGEND

□ SEDIMENT SAMPLE
△ SURFACE WATER SAMPLE
〜 LAKE
RIVER
SWAMP
—— MAJOR ROAD
--- MINOR ROAD
- - - DIRT ROAD
==== RAIL ROAD

GRAPHIC SCALE

(IN FEET)
1 inch = 2200 ft.

US EPA ENVIRONMENTAL RESPONSE TEAM
RESPONSE ENGINEERING AND ANALYTICAL CONTRACT
68-03-3482
W.D.# 3347-21-01-4305
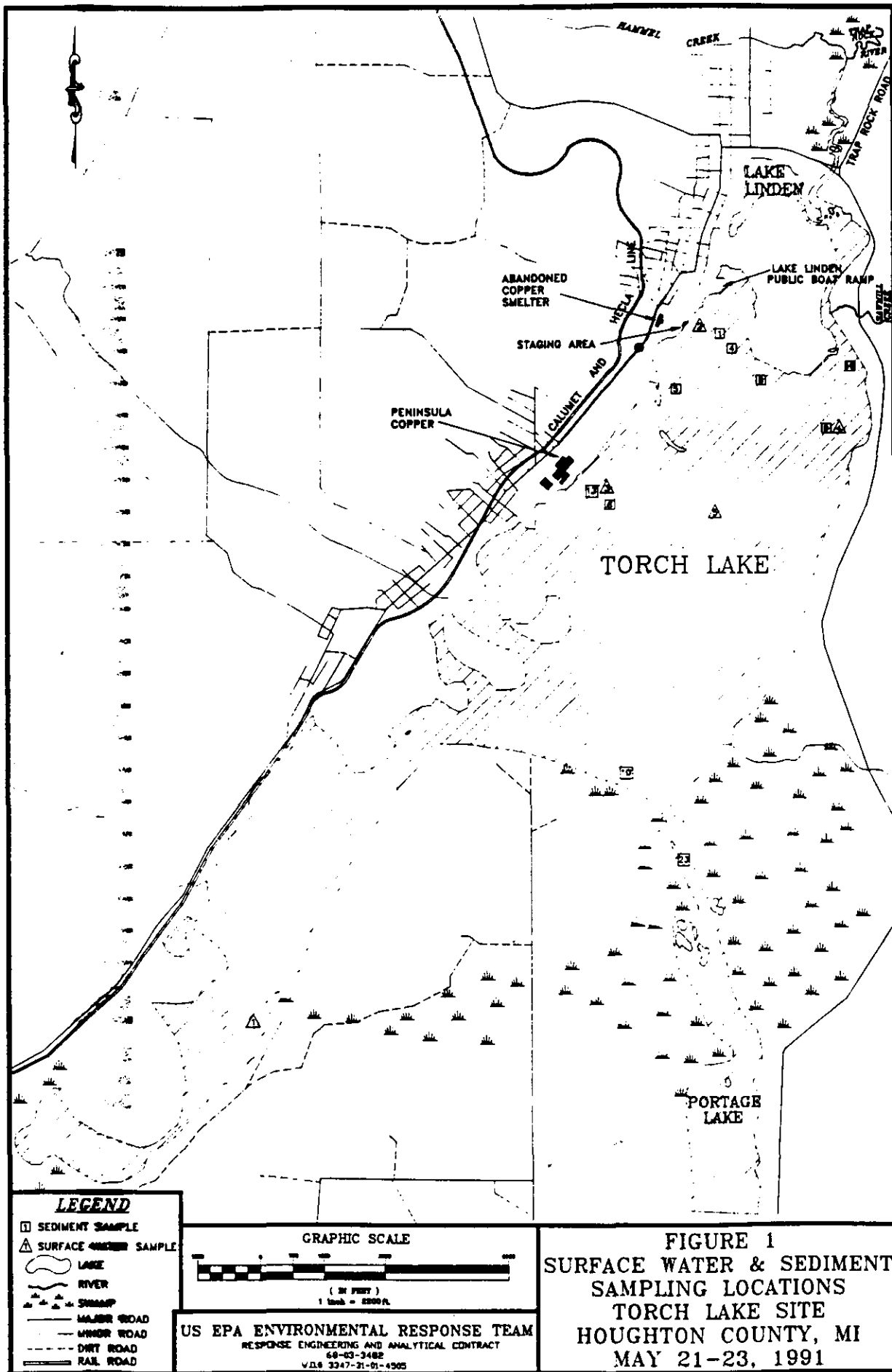
FIGURE 1
SURFACE WATER & SEDIMENT
SAMPLING LOCATIONS
TORCH LAKE SITE
HOUGHTON COUNTY, MI
MAY 21-23, 1991
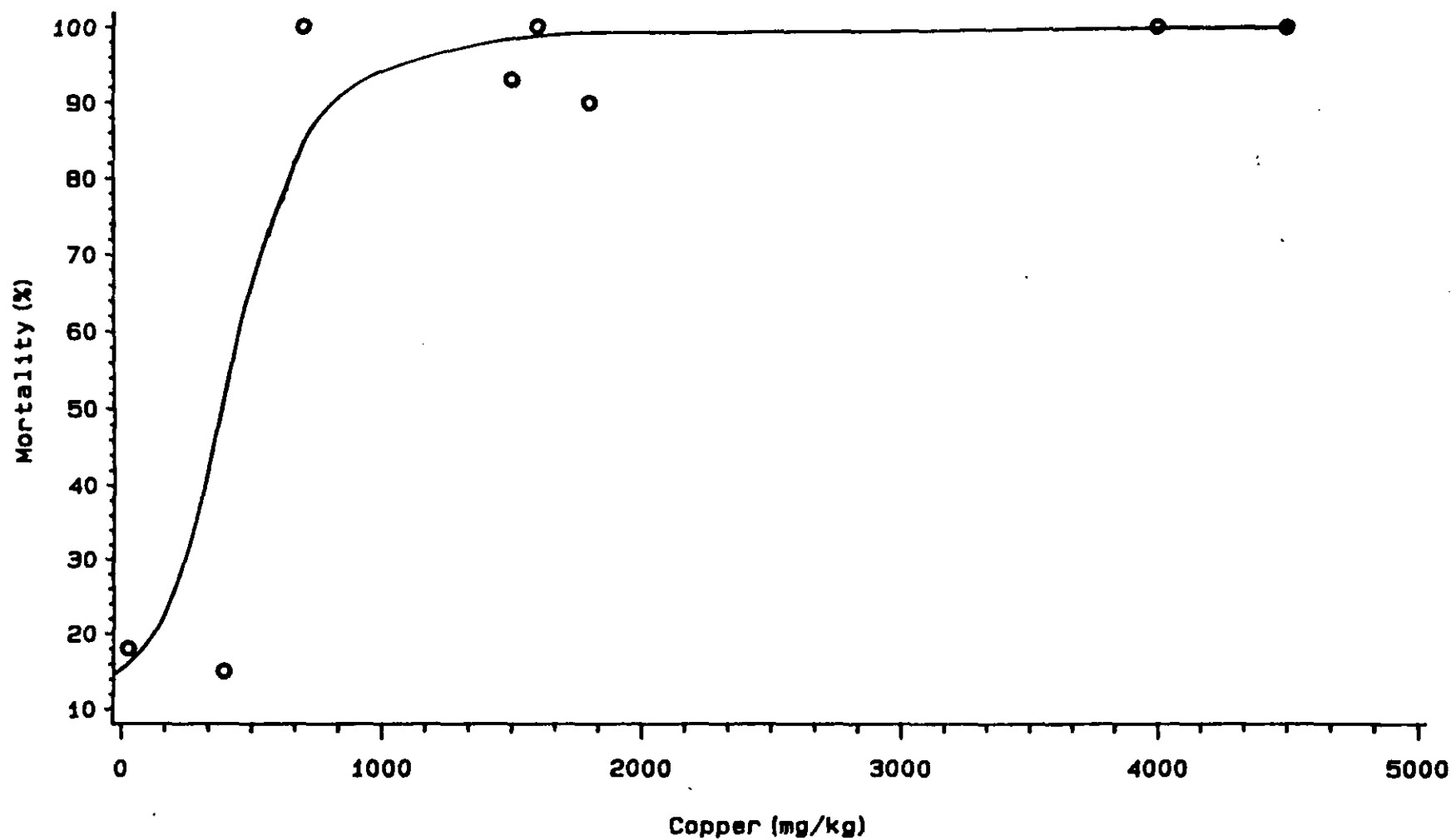
Map labels: HAMMEL CREEK, TRAP ROCK ROAD, LAKE LINDEN, LAKE LINDEN PUBLIC BOAT RAMP, ABANDONED COPPER SMELTER, HECLA LINE, STAGING AREA, CALUMET AND, PENINSULA COPPER, TORCH LAKE, PORTAGE LAKE

Figure 2
Dose–Response Curve for *Hyalella azteca*
to Sediment–Bound Copper
Torch Lake Site, Houghton, MI
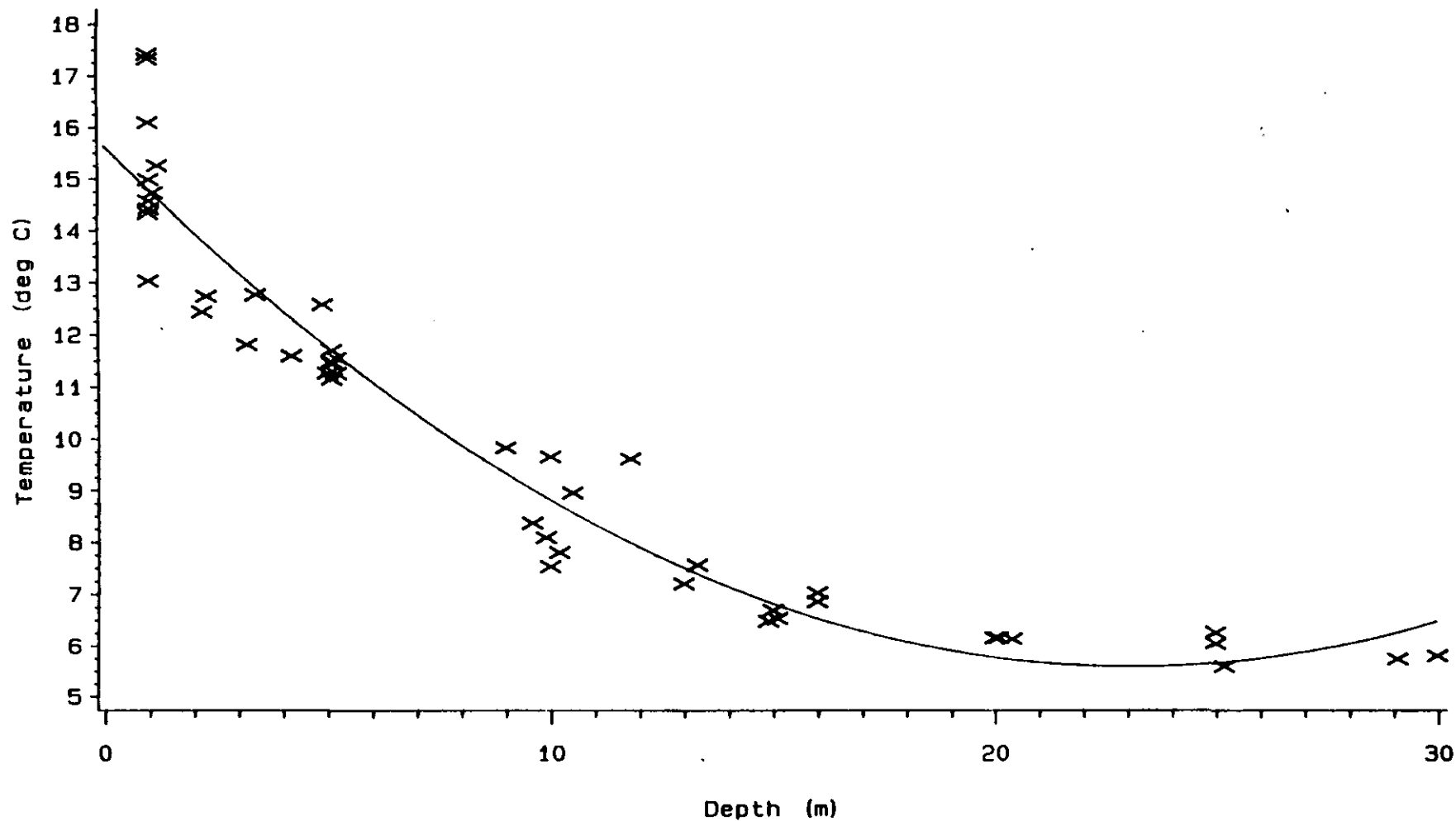
US EPA ENVIRONMENTAL RESPONSE TEAM
RESPONSE ENGINEERING ANALYTICAL CONTRACT
68–03–3482

W.O.# 3347–31–01–4505   November, 1991

Figure 3
Approximate Temperature Profile of
Torch Lake on May 22, 1991
Torch Lake Site, Houghton, MI.

US EPA ENVIRONMENTAL RESPONSE TEAM
RESPONSE ENGINEERING ANALYTICAL CONTRACT
68-03-3482

W.O.# 3347-31-01-4505   November, 1991

Table 1. Results of TAL Metals Analysis of Sediment Collected May 21-23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

(Units in mg/kg)

Location	1	4	5	6	8	9	10	13	19	23	MDL
Aluminum	49000	15?00	18000	45000	49000	48000	1000	42000	14000	13000	50
Antimony	0.5U	0.5U	0.5U	0.7	0.5U	0.5U	0.5U	4	0.5U	0.5U	0.5
Arsenic	24	36	9	410	16	19	1	580	1	8	0.5
Barium	140	91	120	190	120	160	9	220	19	19	1.0
Cadmium	3	2.5U	2.5U	7	3	2.5U	2.5U	16	2.5U	2.5U	2.5
Calcium	23000	8?0	3900	23000	24000	25000	320	23000	15000	6600	5
Chromium	73	33	22	120	79	72	5U	130	22	22	5
Cobalt	50	18	13	52	57	52	5U	40	12	14	5
Copper	4500	4?0	1600	12000	1800	1500	24	23000	390	700*	5
Iron	43000	44?0	23000	44000	34000	40000	1800	56000	9300	13000	5
Lead	230	130	53	1100	79	61	10U	2000	10U	14	10
Magnesium	34000	9?0	6700	32000	38000	34000	260	25000	4600	9100	5
Manganese	1100	3?0	440	950	1400	1600	24	750	320	170	5
Mercury	0.33	0.32	0.12	0.38	0.22	0.16	0.02U	0.46	0.02	0.14	0.02
Nickel	110	46	32	120	110	110	5U	150	36	30	5
Potassium	1100	1?0	2500	1100	680	570	85	970	150	390	5
Selenium	0.5U	1	0.5U	0.5U	0.5U	0.5U	0.5U	1	0.5U	0.5U	0.5
Silver	7	3	4	13	5	4	2.5U	23	3	2.5U	2.5
Sodium	760	460	270	1400	670	620	94	1100	240	290	10
Vanadium	150	63	43	150	150	130	2.5U	100	49	16	2.5
Zinc	280	170	100	770	230	210	·6	1200	63	64	1
Total Metal Burden	157547	8?61	53296	162383	152108	152108	3623	176284	44205	43437	

MDL - Denotes method detection limit
U - Denotes not detected above MDL
* - Denotes mean of sample analyzed in triplicate

**Table 2.** Comparison of Copper Concentrations Determined by Atomic Absorption (A.A.) Analysis and XRF Analysis of Sediment Collected May 21-23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

(Units in mg/kg)

Location	Copper Concentration by A.A.	Copper Concentration by XRF
1	4500	4400
4	4000	5100
5	1600	2800
6	12000	14000[#]
8	1800	2000
9	1500	1500
10	24	ND
13	23000	24000[#]
19	390	420
23	700[•]	990

[#] - Denotes sample concentration above XRF calibration range
[•] - Denotes mean of sample analyzed in triplicate

Table 3. Correlations Between Sediment-Bound Metals in Samples Collected May 21 - 23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

	Al	As	Ba	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Hg	Ni	K	Ag	Na	V	Zn
Al			X		X	X	X		X		X	X	X	X			X	X	
As			X	X		X		X		X			X	X		X	X		X
Ba				X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Ca						X	X		X		X	X		X			X	X	
Cr							X	X	X	X	X		X	X		X	X	X	X
Co									X		X	X		X			X	X	
Cu									X	X			X	X		X	X		X
Fe										X	X		X	X		X	X	X	X
Pb													X	X		X	X		X
Mg												X		X			X	X	
Mn														X				X	
Hg														X		X	X	X	X
Ni																X	X	X	X
K																			
Ag																	X		X
Na																		X	X
V																			
Zn																			

X - Denotes significant positive correlation (P<0.05)
Note: A. Shaded areas prevent duplication of data
B. Sb and Se not utilized in correlation due to absence of deviation throughout data set

Table 4. Results of Particle Size Distribution Analysis of Sediment Collected May 21 - 23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

Location	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
1	1.37	7.34	20.27	70.93
4	0.00	24.95	44.49	30.55
5	0.00	45.07	29.73	25.20
6	0.00	8.77	29.45	62.78
8	0.00	5.82	18.94	75.35
9	0.00	4.99	22.53	72.48
10	0.00	97.59	2.41 % unaccounted [n]	
13	0.00	8.54	39.65	51.81
19	0.00	93.48	1.93	4.69 % unaccounted[n]
23	0.57	42.66	33.34	23.43

[n] - Denotes this portion of the sample could not be accounted by the analyst

Table 5. Results of Total Organic Carbon Analysis of Sediment Collected May 21 - 23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

(Units in mg/kg)

Location	1	4	5	6	8	9	10	13	19	23
Total Organic Carbon	31000	130000	41000	24000	20000	14000	870	35000	2700	27000

Table 6. Results of *Hyalella azteca* 28-day Solid Phase Toxicity Testing for Sediment
Collected on May 21 -23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

Location	Mortality at 72 hours (percent)@	Mean Survival (percent)	Mean Individual Weight (mg)	Mean Individual Length (mm)
1	5	0	A	A
4	7	0	A	A
5	0	0	A	A
6	50	0	A	A
8	0	10	0.062	3.107
9	7	7	0.055	3.055
10	2	82	0.378	5.023
13	31	0	A	A
19	5	85	0.187	4.517
23	2	0	A	A
Sediment Control	0	82	0.366	4.676

@ - Denotes non-definitive data, to be viewed with discretion
A - Denotes data cannot be aquired due to 100 percent mortality

Table 7. Comparison of *Hyalella azteca* 28-day Solid Phase Toxicity Testing and A.A. Copper Concentration
Results for Sediment Collected on May 21 -23, 1991
Torch Lake Site
Houghton County, Michigan
November, 1991

Location	Mean Survival (percent)	Copper Concentration by A.A. (mg/kg)
1	0	4500
4	0	4000
5	0	1600
6	0	12000
8	10	1800
9	7	1500
10	82	24
13	0	23000
19	85	390
23	0	700*

* - Denotes mean of sample analyzed in triplicate

Table 8. Results of TAL Metals Analysis of Surface Water Collected May 22, 1991
Torch Lake Site
Houghton Michigan
November, 1991

(Units in ug/l)

Location	1	2	3	4	5	Kemmerer Rinsate	MDL
Barium	19	13	13	15	13	10U	10
Calcium	13000	13000	13000	13000	13000	180	50
Copper	52	50U	50U	50U	50U	50U	50
Iron	590	160	140	140	220	53	50
Lead	8	7	5	5U	5U	5U	5
Magnesium	3300	3100	3100	3100	3000	50U	50
Manganese	81	50U	50U	50U	50U	50U	50
Mercury	0.4	0.4U	0.4U	0.6	0.4U	0.4U	0.4
Potassium	670	700	880	1500	930	56	50
Sodium	8600	9200	9500	10000	9500	100U	100
Zinc	10U	10U	10U	10U	10U	11	10
Hardness (mg/l)*	46.05	45.23	45.23	45.23	44.81		

MDL - Denotes method detection limit
ND - Denotes not detected
* - Denotes reported as $CaCO_3$

Table 9. Water Quality Data From Surface Water Sampling Locations at Torch Lake Site
on May 22, 1991
Houghton County, Michigan
November, 1991

Location	Depth (meters)	Temperature (^{0}C)	Dissolved Oxygen (mg/l)	Oxygen Saturation (percent)	pH	Conductivity (mmhos/cm)	Oxidation Reduction Potential (v)
1	1.2	15.24	11.57	114	7.84	0.158	0.190
1	5.1	11.69	11.34	106	7.51	0.156	0.204
1	9.6	8.36	11.27	100	7.38	0.156	0.209
1	16.0	7.02	11.23	93	7.30	0.154	0.212
2	1.0	13.02	12.11	114	7.96	0.165	0.181
2	2.2	12.43	11.97	112	7.56	0.162	0.170
2	3.2	11.80	11.82	109	7.79	0.161	0.172
2	4.2	11.58	11.74	107	7.76	0.162	0.173
3	1.0	17.40	11.75	122	8.09	0.159	0.193
3	5.0	11.25	11.65	106	7.58	0.160	0.211
3	9.0	9.82	11.78	103	7.53	0.163	0.214
4	1.0	17.30	11.97	122	8.14	0.173	0.146
4	4.9	12.56	11.05	105	7.88	0.163	0.160
4	9.9	8.08	11.59	98	7.52	0.160	0.170
4	13.3	7.55	11.54	96	7.48	0.159	0.170
5	1.0	16.08	12.11	121	8.22	0.163	0.146
5	5.2	11.54	11.68	107	7.81	0.160	0.150
5	10.0	7.52	11.57	97	7.57	0.160	0.157
5	15.1	6.53	11.61	94	7.56	0.159	0.155
5	20.0	6.15	11.68	94	7.56	0.159	0.154
5	25.2	5.58	11.54	92	7.49	0.158	0.157
5	30.0	5.79	11.64	93	7.50	0.159	0.151

Note: Salinity at all locations and depths was 0.0 ^{0}/oo

Table 10. Water Quality Data From Random Locations Within Torch Lake Site on May 22, 1991
Houghton County, Michigan
November, 1991

Location	Depth (meters)	Temperature (^{0}C)	Dissolved Oxygen (mg/l)	Oxygen Saturation (percent)	pH	Conductivity (mmhos/cm)	Oxidation Reduction Potential (v)
1	1.0	14.97	11.57	112	8.18	0.167	0.192
1	2.3	12.72	11.83	111	8.02	0.162	0.193
1	3.4	12.75	11.81	111	7.96	0.162	0.197
2	1.0	14.41	11.93	116	8.28	0.164	0.176
2	5.1	11.47	11.84	109	7.84	0.161	0.193
2	11.8	9.60	11.25	100	7.71	0.160	0.198
3	1.0	14.56	11.93	116	8.31	0.165	0.181
3	5.1	11.43	11.82	109	7.95	0.161	0.197
3	10.0	9.64	11.57	101	7.71	0.163	0.208
3	13.0	7.20	11.69	96	7.73	0.158	0.209
3	16.0	6.85	12.28	101	7.84	0.161	0.207
4	1.0	14.32	11.97	116	8.31	0.160	0.194
4	5.2	11.25	11.76	107	7.98	0.159	0.205
4	10.5	8.94	11.57	100	7.72	0.159	0.218
4	15.0	6.69	11.55	95	7.68	0.160	0.222
4	20.1	6.15	11.55	94	7.72	0.158	0.221
4	25.0	6.25	11.47	93	7.77	0.158	0.220
5	1.1	14.72	11.75	112	8.42	0.158	0.180
5	5.1	11.14	11.54	103	7.95	0.158	0.192
5	10.2	7.79	11.68	98	7.75	0.156	0.202
5	14.9	6.48	11.70	95	7.67	0.158	0.207
5	20.4	6.13	11.59	94	7.68	0.157	0.207
5	25.0	6.04	11.51	93	7.71	0.158	0.205
5	29.1	5.73	11.68	93	7.74	0.158	0.200

Note: Salinity at all locations and depths was 0.0 ^{0}/oo